Development of Columbia Leading Edge Reconstruction System – Abstract

After the loss of Columbia in 2003, the Columbia Accident Investigation Board and NASA KSC directed personnel at the Launch Equipment Test Facility to design and build high fidelity mock-ups of Columbia's left wing leading edges. These leading edge segments, constructed of reinforced carbon-carbon, were a major point of inquiry by the investigation team. The LETF engineers developed a concept of building a clear Lexan panel with an aluminum support structure ten percent larger than the original panel. The leading edge debris are attached to the Lexan panels and both the front and back side of each panel are visible for inspection. The entire assembly can be rotated, to provide visual access to the entire panel. Six carts were fabricated to support the thirteen panels. These carts could be set up in order, next to each other, to provide the desired inspection access. The carts and attached debris are currently located in the Vehicle Assembly Building at KSC.

Introduction

After the Columbia accident, investigators began to focus their attention to the leading edge of the left wing of the shuttle. Ascent photographs and various descent data pointed to a potential failure to the leading edge, comprised of a number of components including the panels made of Reinforced Carbon Carbon (RCC); a so-called t-seal that fills the gap between the leading edge panels; or a part known as a carrier panel that covers the joint between the leading edge panels and the wing's surface. Figure 1 potentially shows the foam debris from the External Tank which appeared to strike the left wing leading edge.

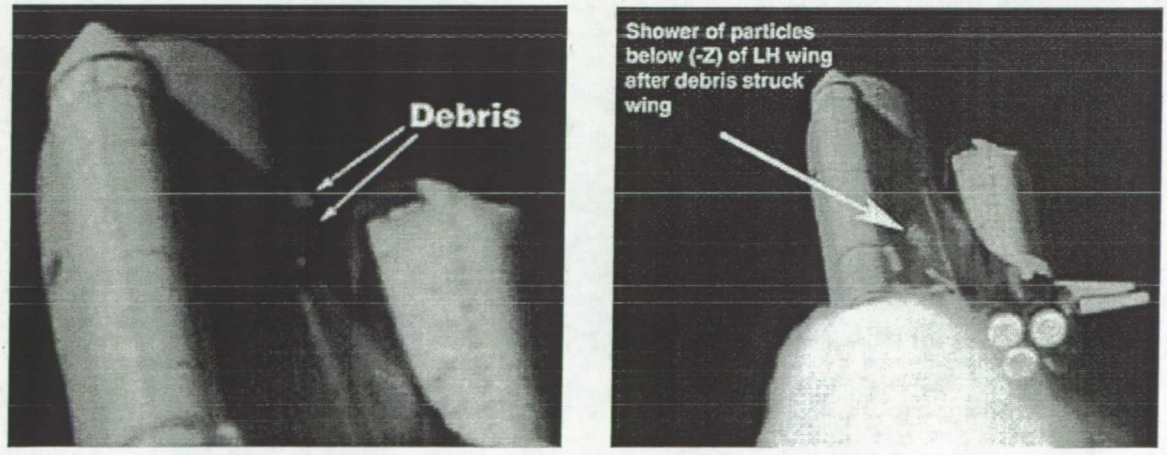

Figure 1 Debris Striking Leading Edge of Columbia

Each wing of the shuttle has 22 leading-edge panels that can withstand reentry temperatures of 3,000 degrees. Figures 2 and 3 illustrate the location and elements of the leading edge components.

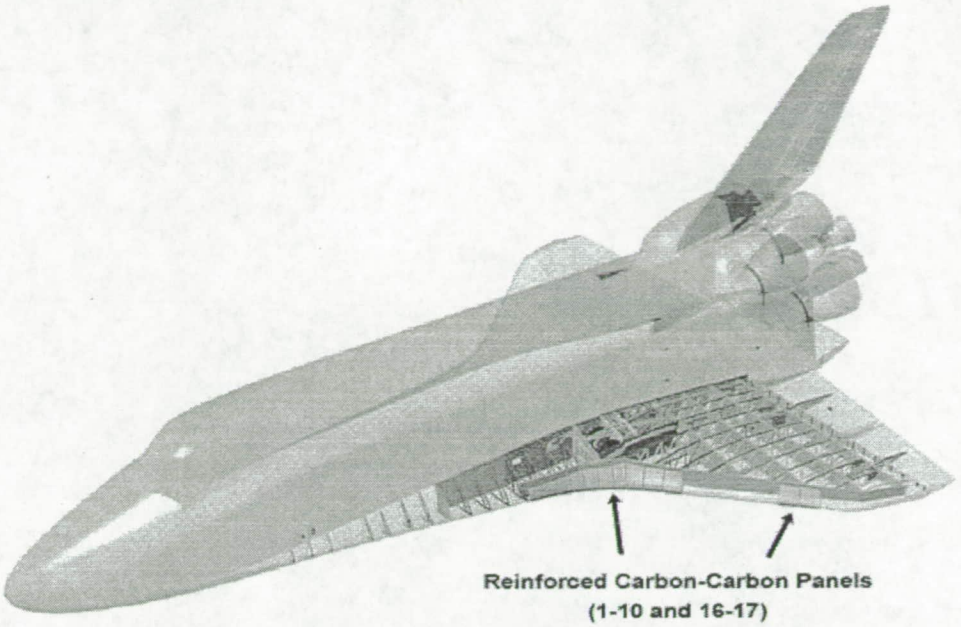

Figure 2 Location of Left Wing Components

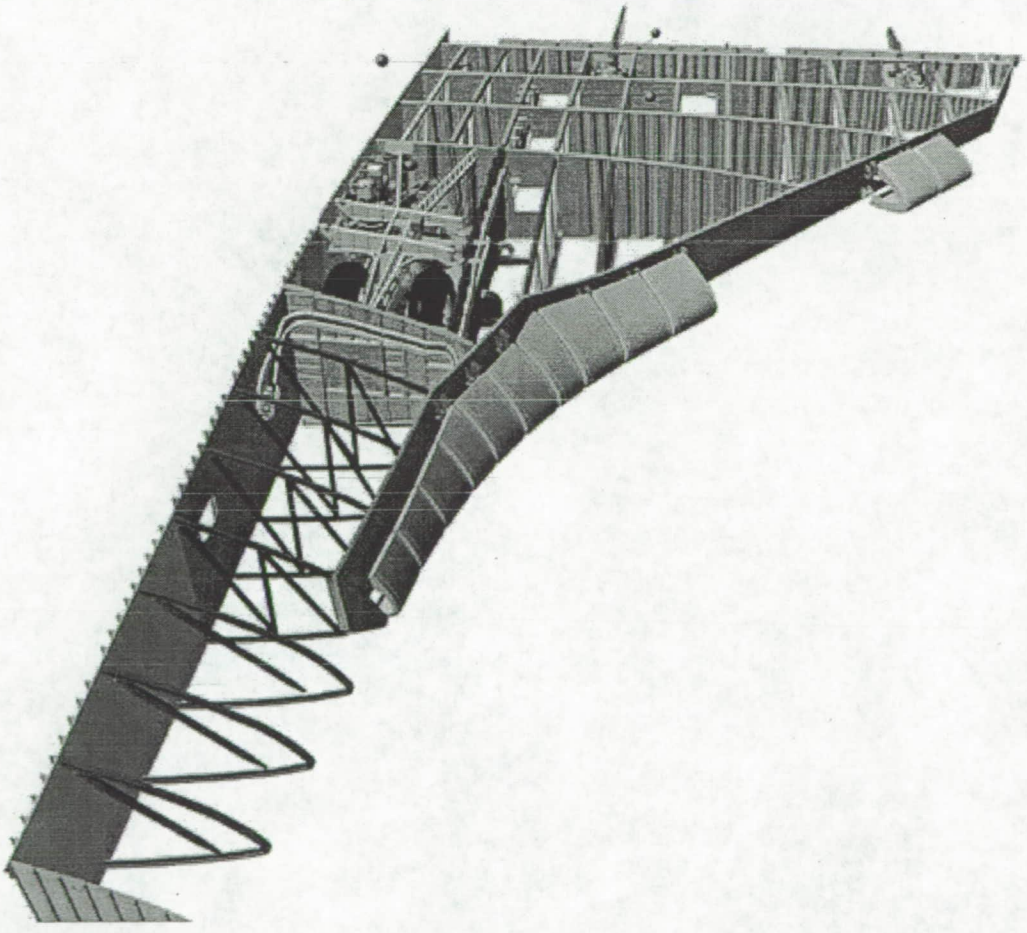

Figure 3 Detail of Left Wing Components (RCC Panels 1-10 and 16-17)

It became important to the Columbia investigators that the debris had to be acquired, documented and investigated, with special attention to the left wing components. In early April 2003, the University-Affiliated Spaceport Technology Development Contract (USTDC) at the Kennedy Space Center was directed to design and fabricate a carrier device to mount the left wing RCC components, providing access and inspection of the debris in all direction.

The Cart Development and Design

Of the 22 panels on the leading edge, investigators were focusing on the middle panels, specifically panels six through eight. Charlie Stevenson (KSC PH) provided direction to design and fabricate six carts to support RCC panels one through thirteen. The requirements included the ability to view and access the panels from the front and back, the ability to line up the panels in order, to attach the RCC panels to a substrate. A concept was developed to provide the desired access as depicted in Figure 4 below.

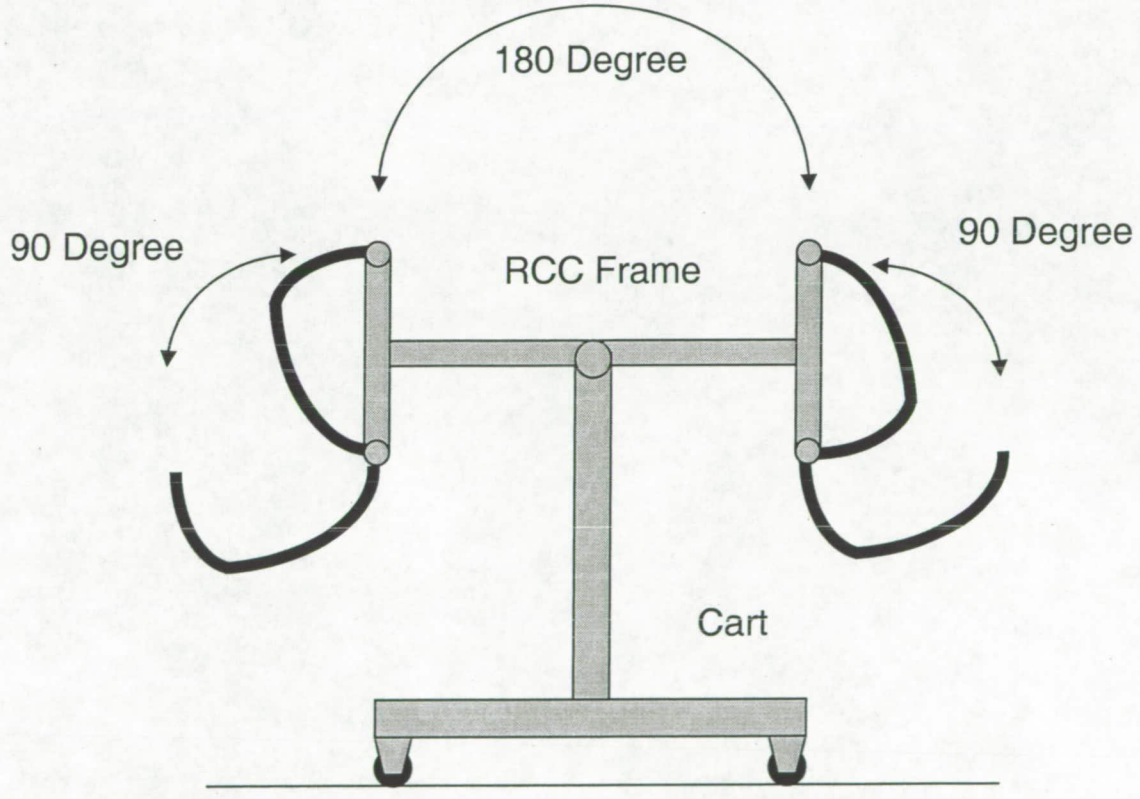

Figure 4 Cart Concept

The carts are mounted on casters, allowing them to be pushed together or separated. The cart frame has a rotational arm, to provide access to the front, back top and bottom of the RCC panel. The cart frame, painted carbon steel was designed to provide a stable platform, under any configuration. This required either two or three RCC panels to be mounted on each cart, to provide out of plane stability. The carts are configured to be pinned together, but the connecting hardware was not installed on the delivered carts.

RCC Carrier Frame and Holder

The RCC carrier frame was designed by taking solid models of the individual RCC panels (panels one through thirteen) and generating a new model for each, which is 10% larger than the original. The outside surface of this enlarged panel became the inside surface of the RCC carrier frame. The carrier frame shown in Figure 5 below, support two panels. The frames are fabricated from 5/8" aluminum plate, and the RCC panel is attached to the clear Lexan panels. The aluminum frames were cut from flat plate using a water-jet cutter in the NASA prototype lab. Figure 5 shows one panel in the normal "UP" position, and the second panel in the "OPEN" position.

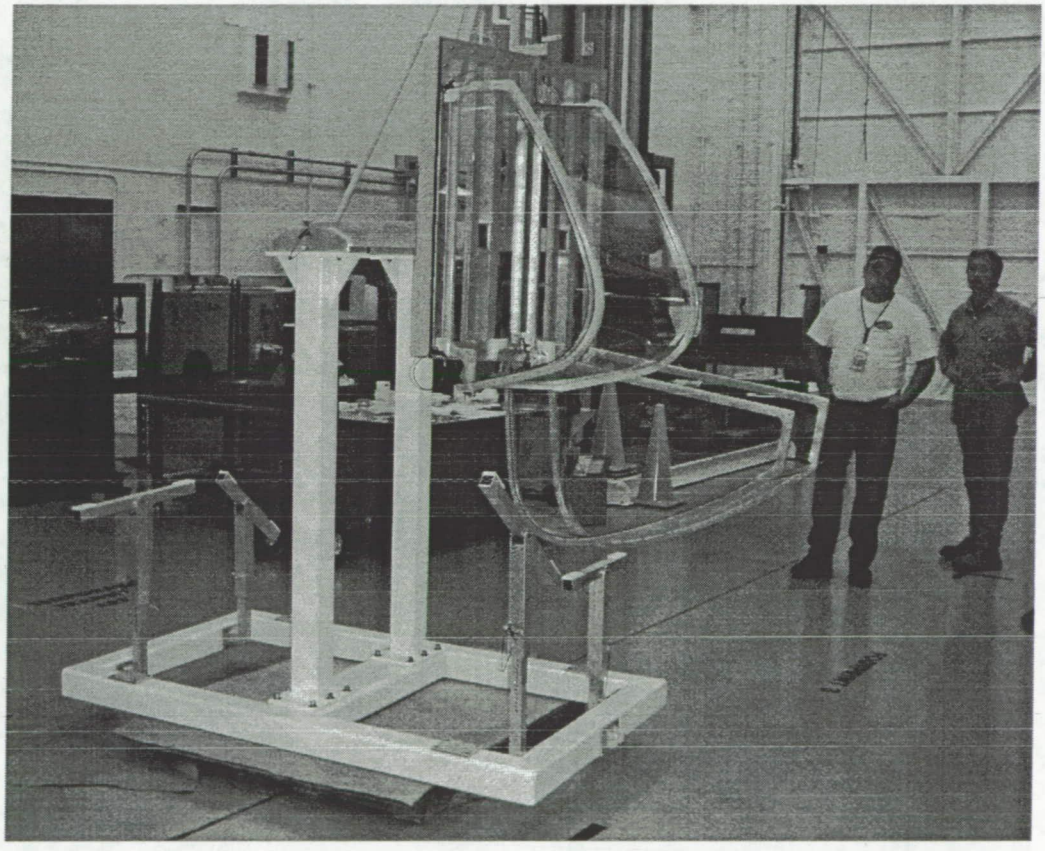

Figure 5 Completed Cart and Carrier Frame

Recovered RCC Panels

Details from the Columbia Accident Investigation Board included:

> *"The recovery of the Columbia debris included over 84,000 individual pieces of Orbiter debris weighing more than 84,900 pounds, representing 38% of the Orbiter's dry weight... The recovered debris allowed investigators to build a three-dimensional reconstruction of Columbia's*

left wing leading edge, which was the basis for understanding the order in which the left wing structure came apart, and led investigators to determine that heat first entered the wing in the location where photo analysis indicated the foam had struck."

The reconstruction of the left wing was instrumental in this analysis. Figures 6 and 7 show a portion of the recovered debris in the carrier frames. In a careful, frame-by-frame, analysis, investigators determined that the foam fell off the bipod area. As it tumbled at about 500 mph relative to the wing, it struck with a footprint about two feet in diameter. It struck the wing's leading edge panels number five, six and seven – a key area of the wing where it angles out less sharply. Investigators found that the left side leading-edge panels are more badly damaged than those on the right side. Steve Altemus, a NASA engineer overseeing the reconstruction, told the CAIB board that the panels on the left side also contained heavy deposits of melted metal. Panel number six, where the foam is believed to have struck is missing.

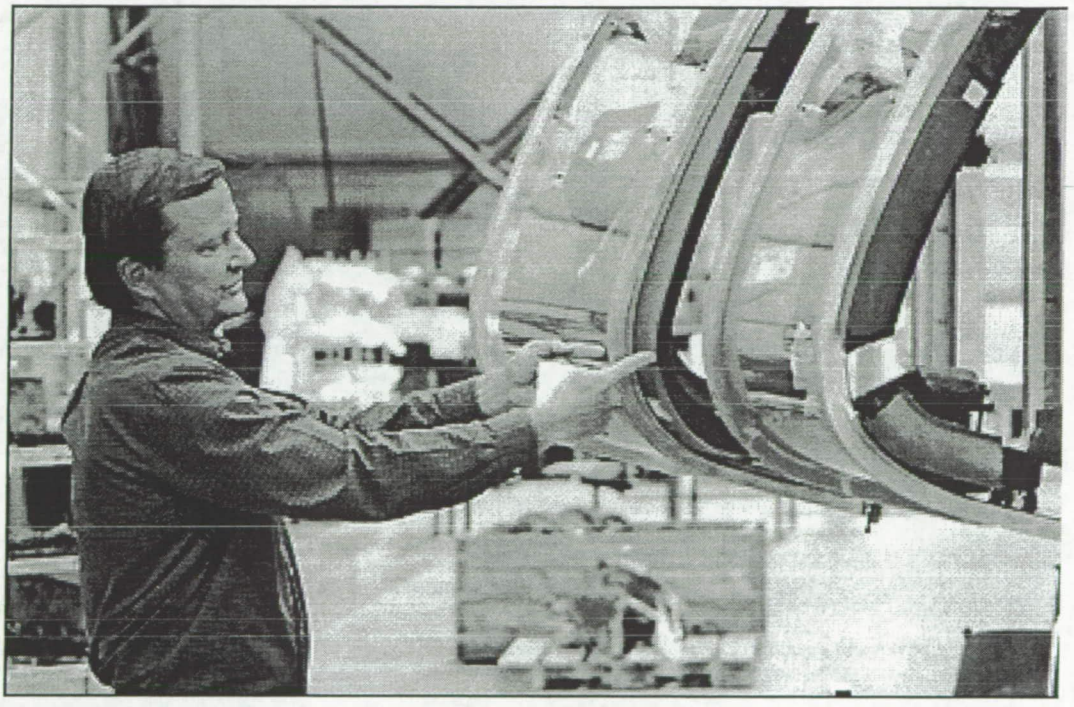

Figure 6 Inspectors Observing Recovered Leading Edge Components

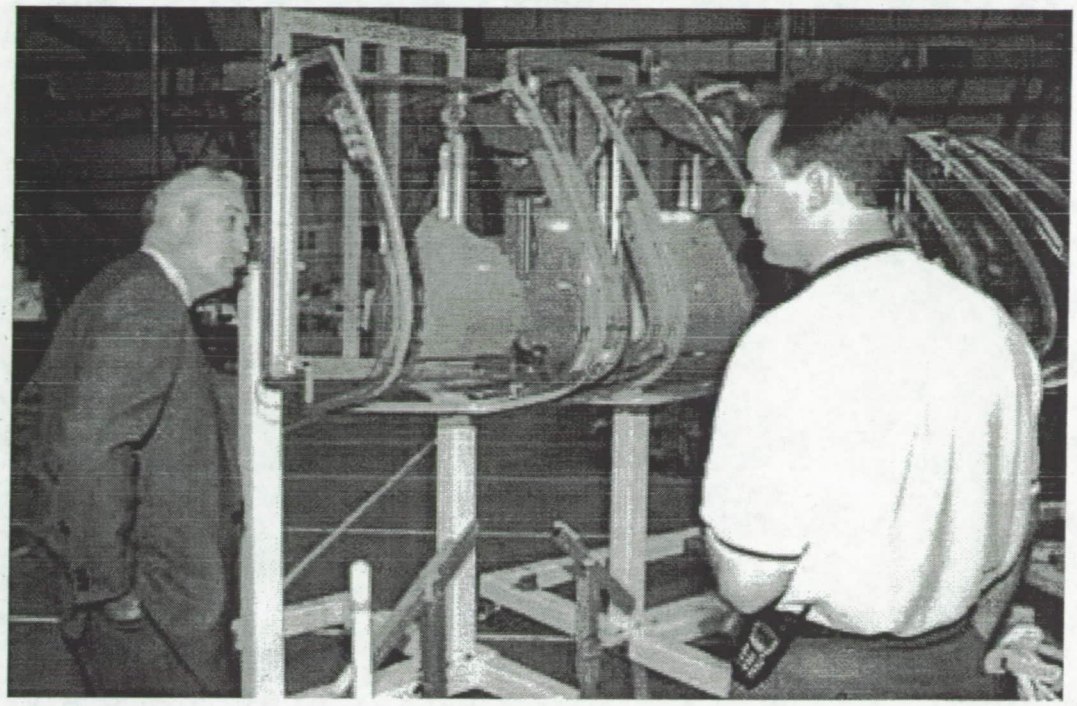

Figure 7 Mr. Sean O'Keefe and Steve Altemus of NASA Observing the Reconstructed Left Wing

USTDC Design and Fabrication Group

The RCC carts were designed, fabricated and assembled by an integrated group of engineers and technicians, including both NASA and contractor personnel. John Trautwein, Joe Moszczienski, and Van Townsend designed the stands and Donna Porter produced production drawings from the designs. The fabrication Team included the following contractor personnel – Art Hendron, Kenneth Heckle, Brad Ayers, Davis Ross, Martin Moneysmith, Andrew Pysz, Darrell March, Davis Early and Matt McCartney. The NASA team included Kevin Boughner, Roger Cartier, Mike Dininny, Jim Nieoff and Dave Rowell. The entire design/build effort was completed in one month.

Conclusion

These carts are currently in use, and the recovered leading edge components are installed the Lexan carriers. The carts provided investigators a clear view of the front and back of the RCC components. The efficient turnaround of the design and fabrication effort helped investigators focus on a failure mechanism. The NASA customers are pleased with the results and our design and fabrication team continues to provide product development activities for various KSC and external customers.

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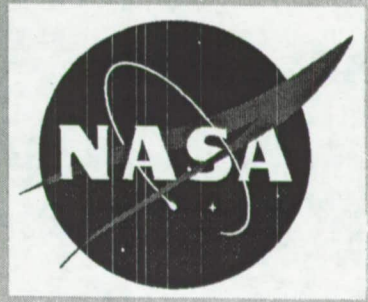
University-Affiliated Spaceport Technology Development Contract

Development of Columbia Leading Edge Reconstruction System

April 20, 2004



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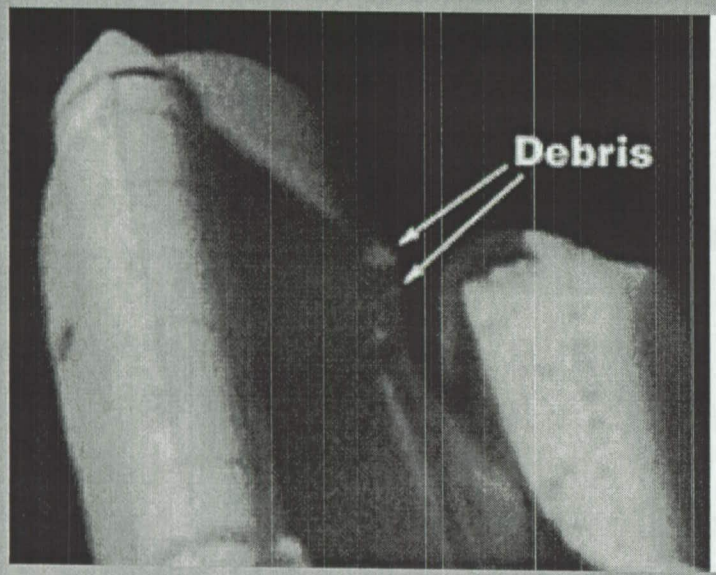
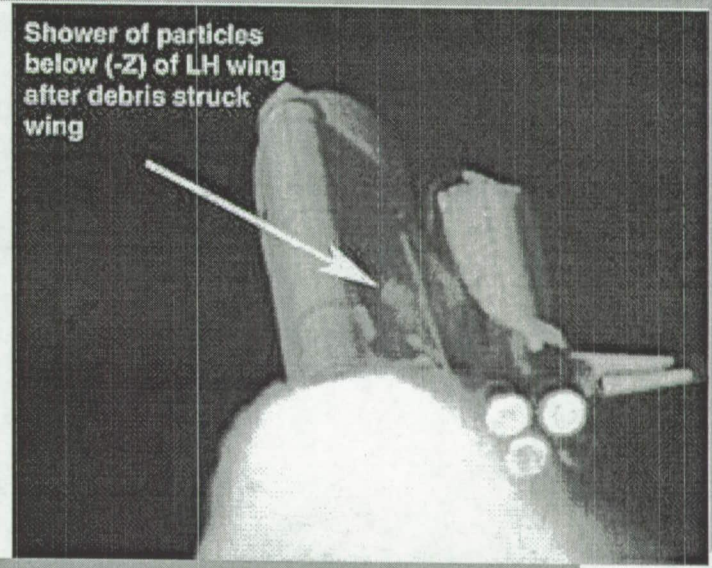
- Shuttle Debris Struck Leading Edge of Left Hand Wing of Columbia on Lift-Off





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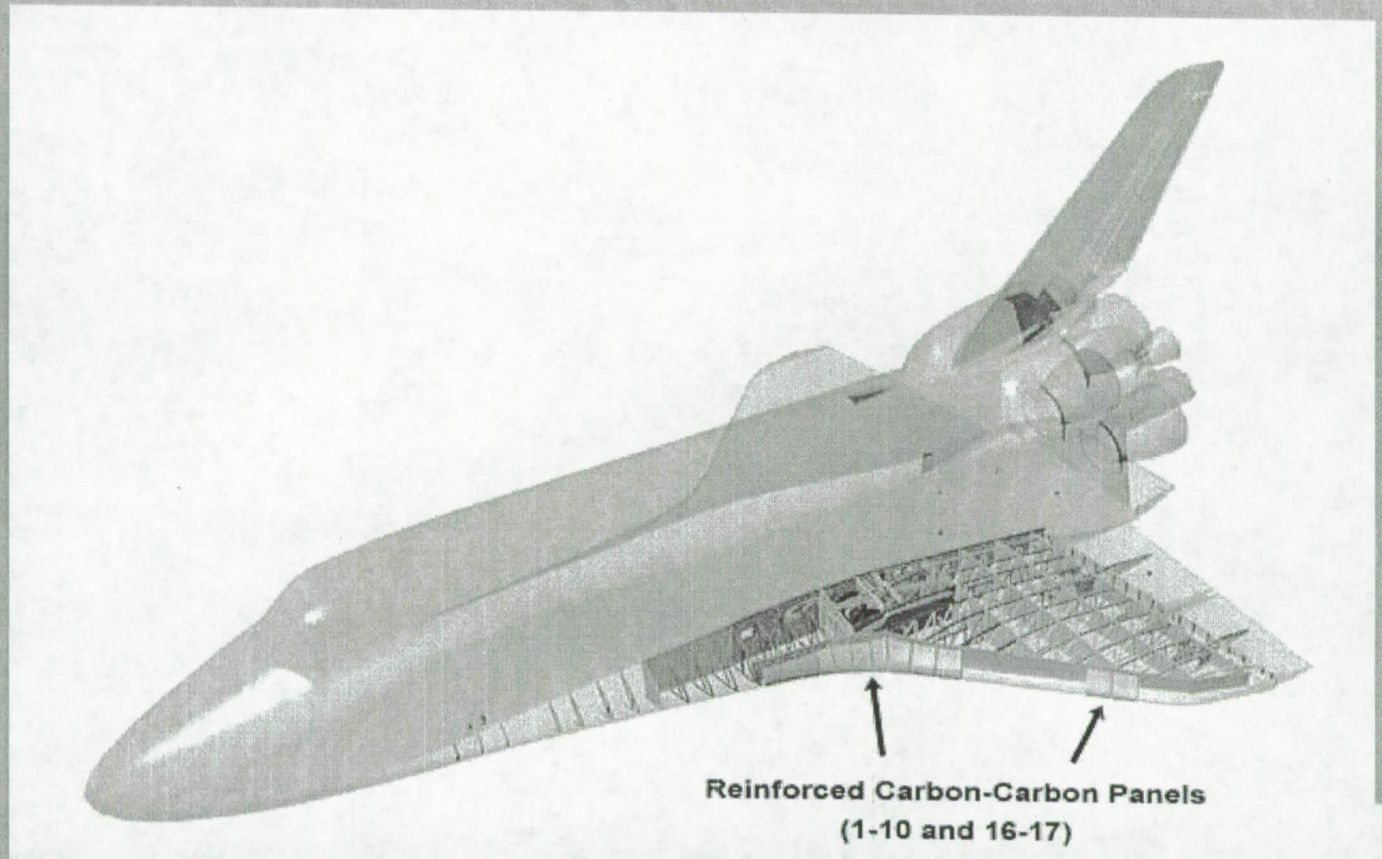

Shuttle RCC Panels Were Suspected of being Damaged

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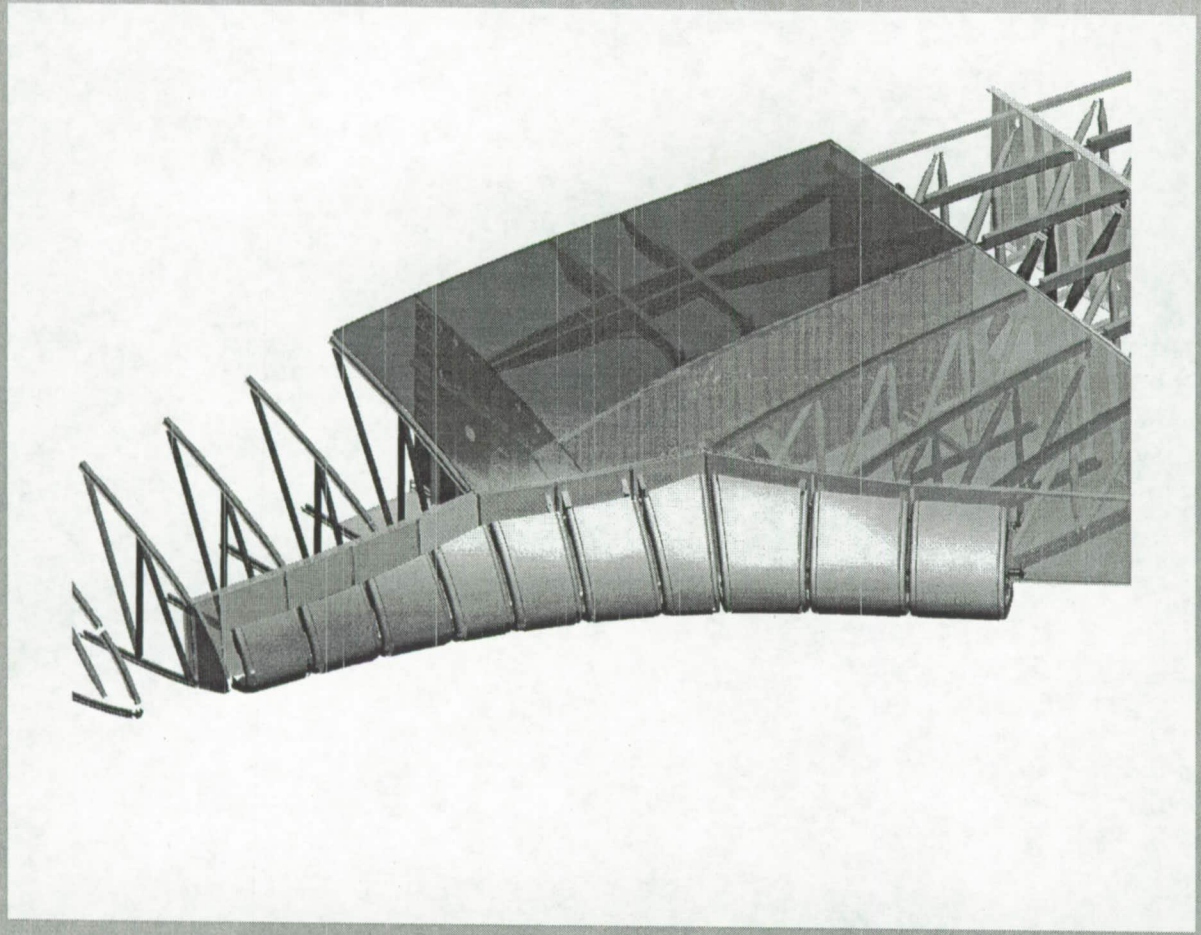

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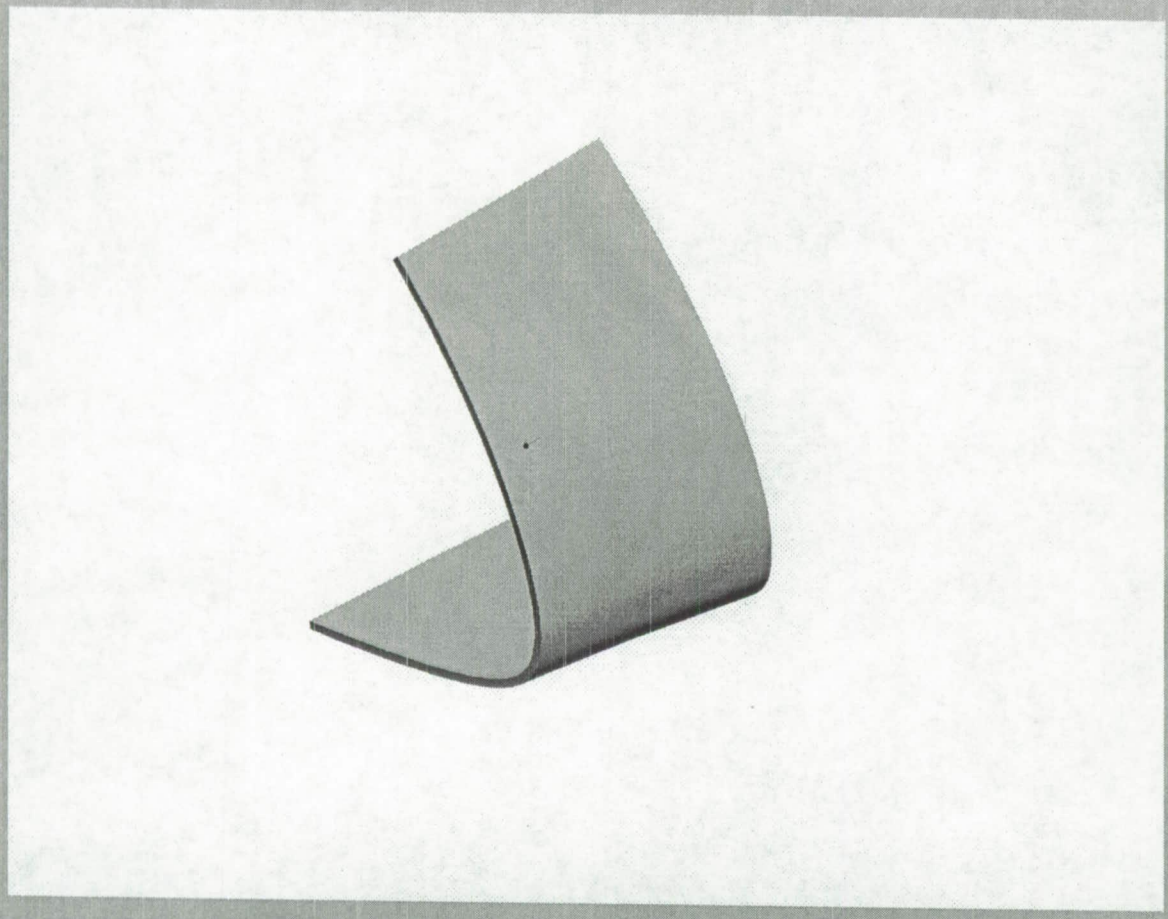

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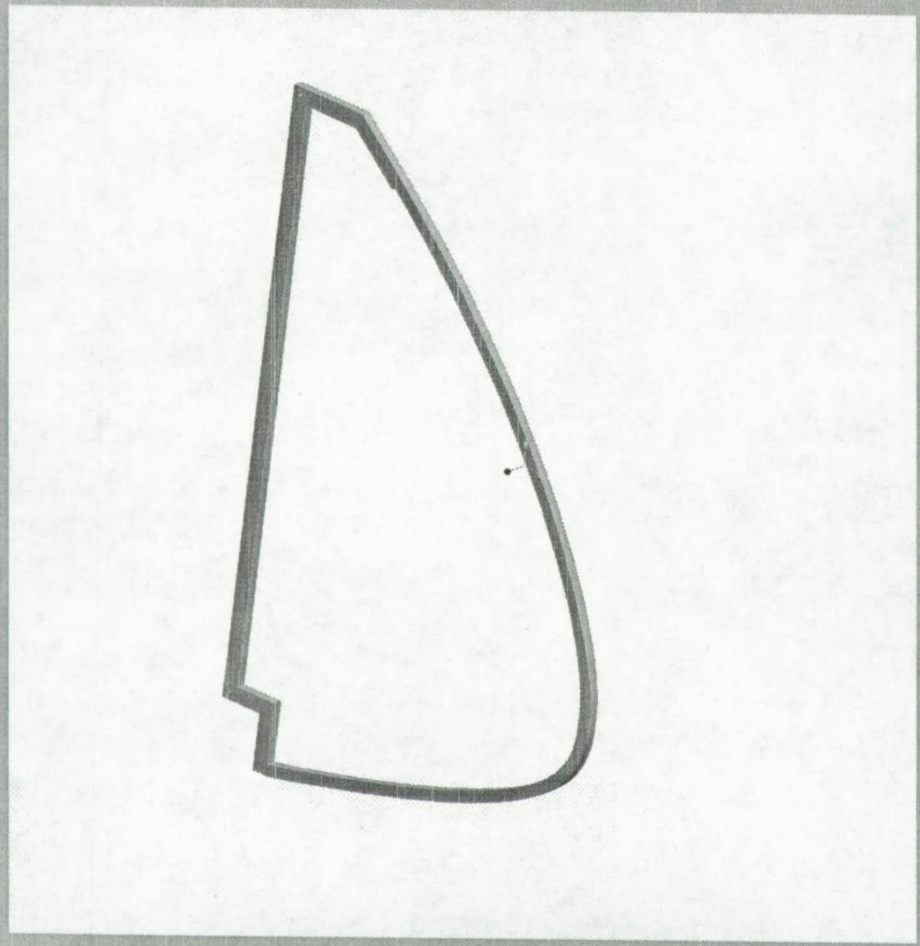

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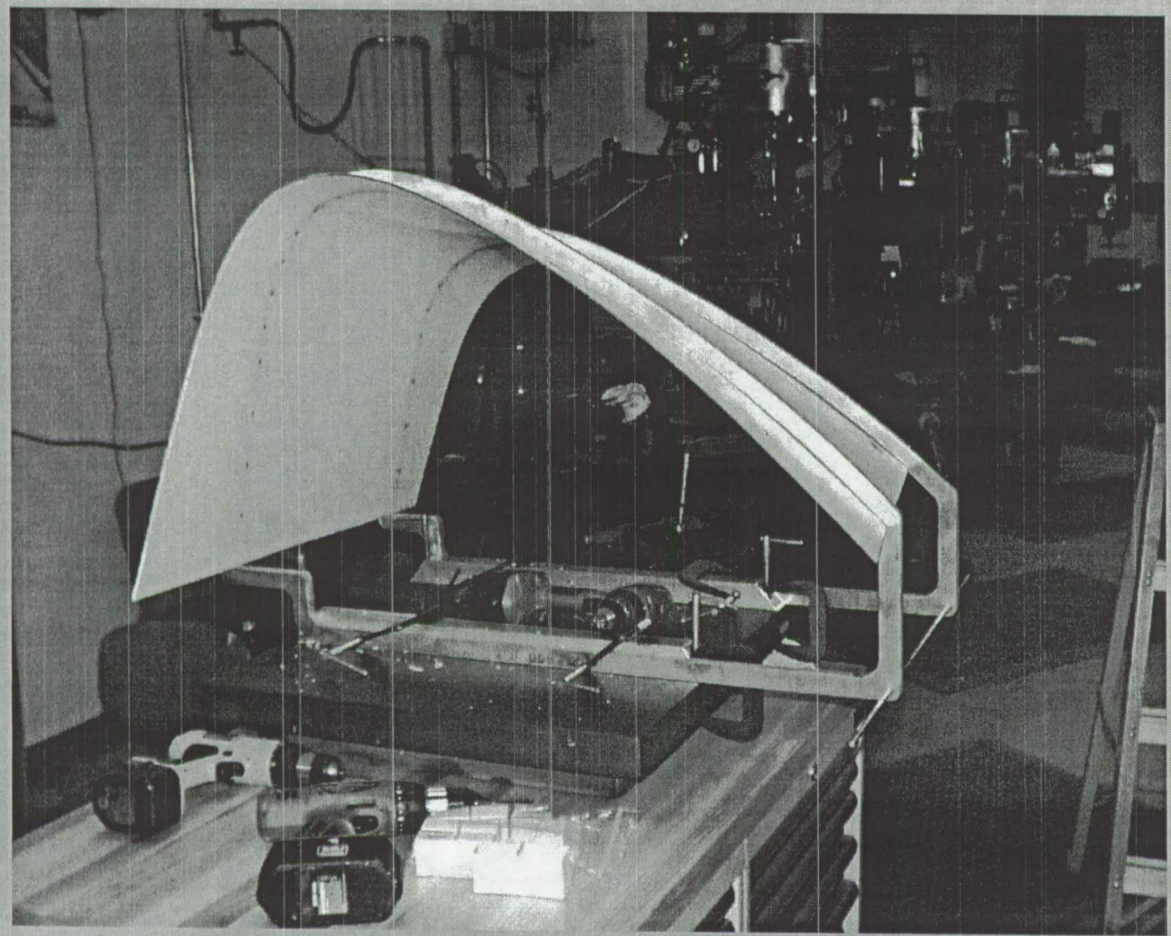

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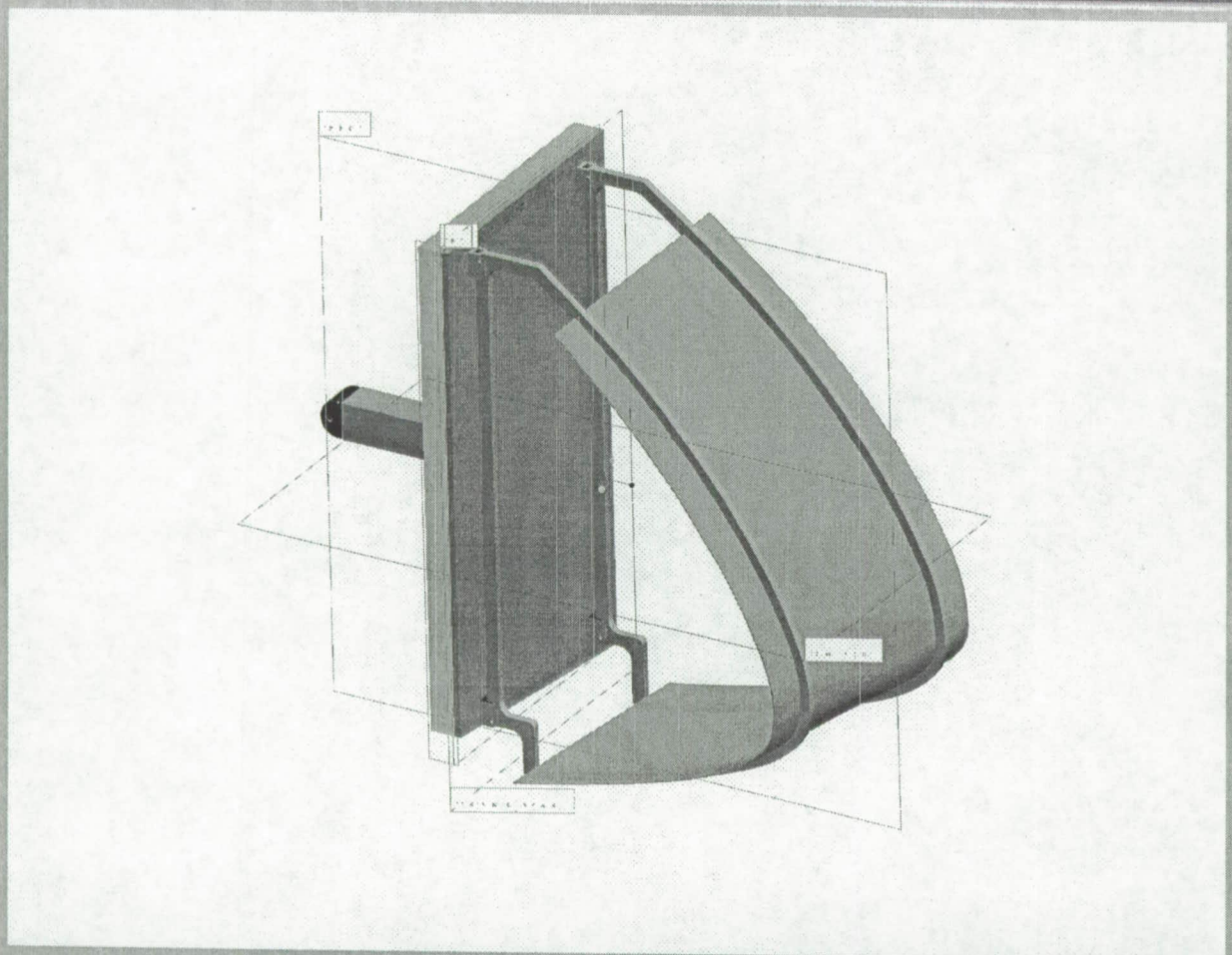

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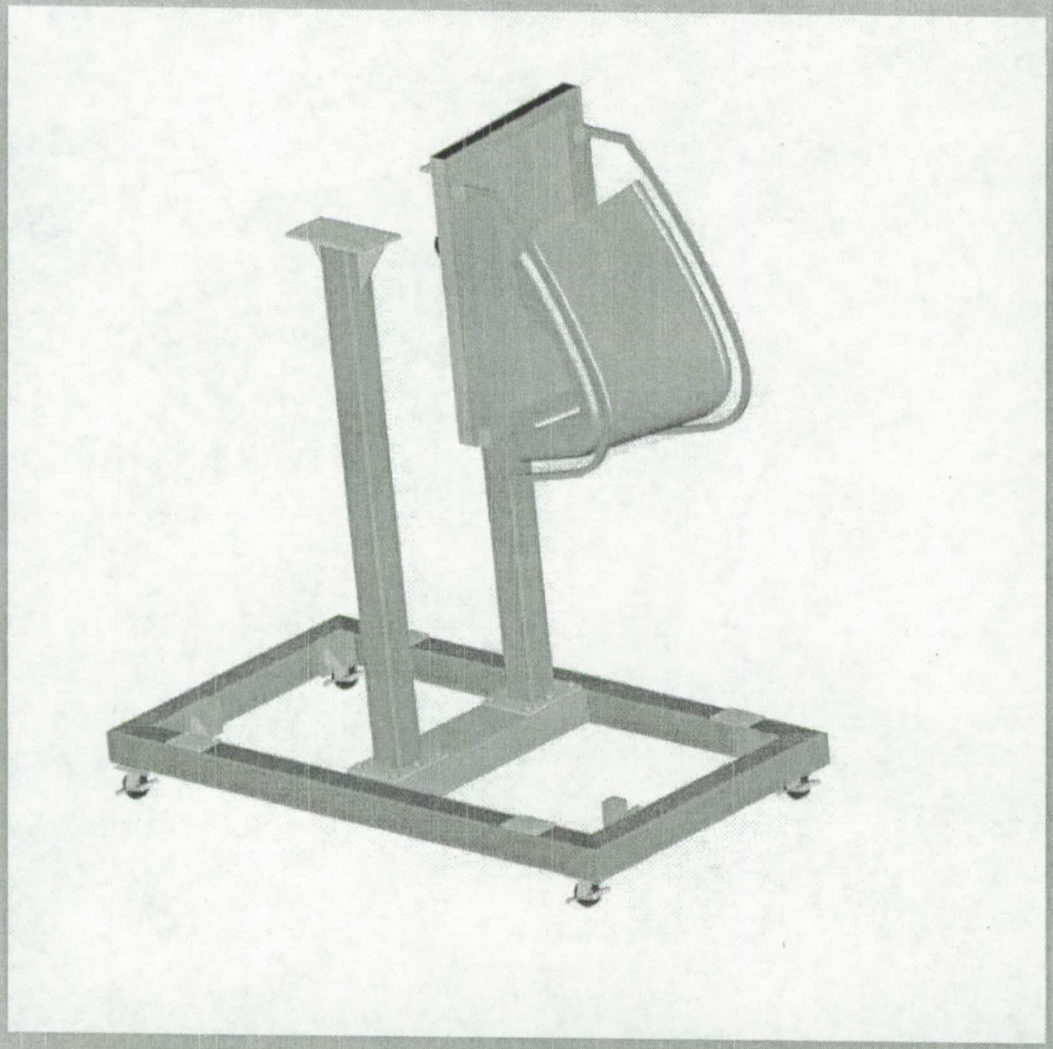

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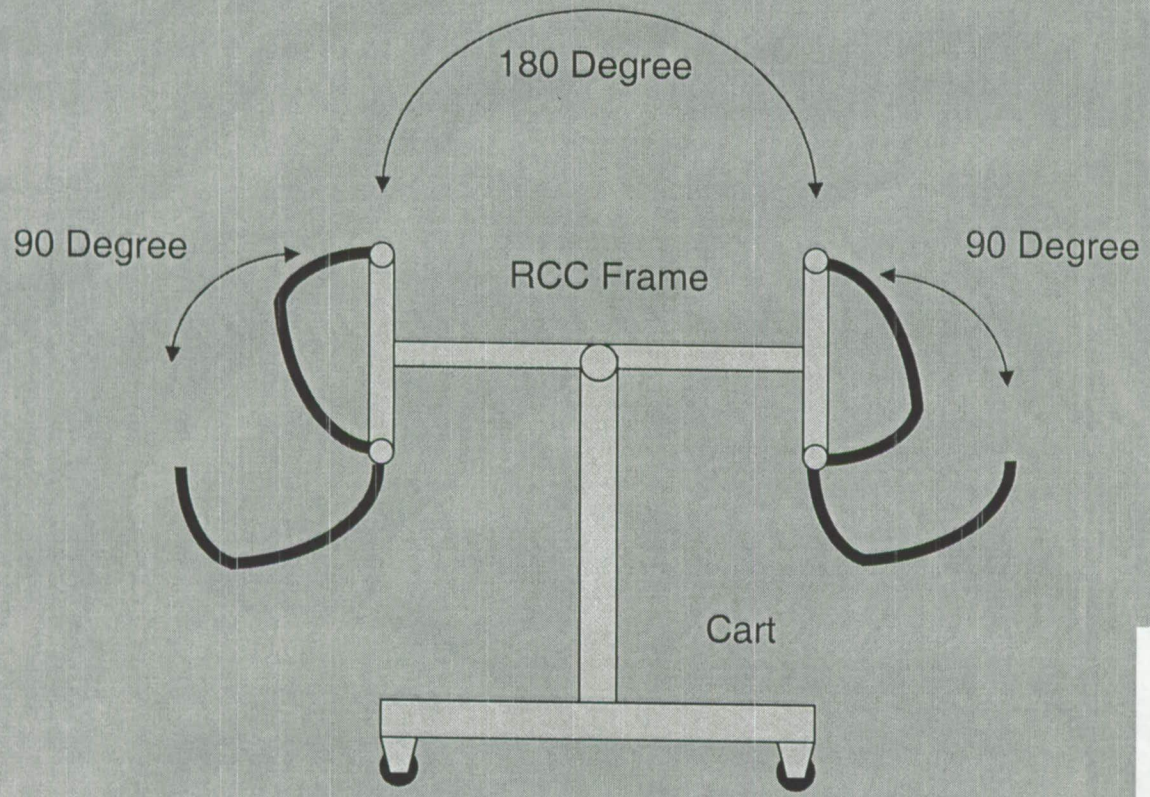

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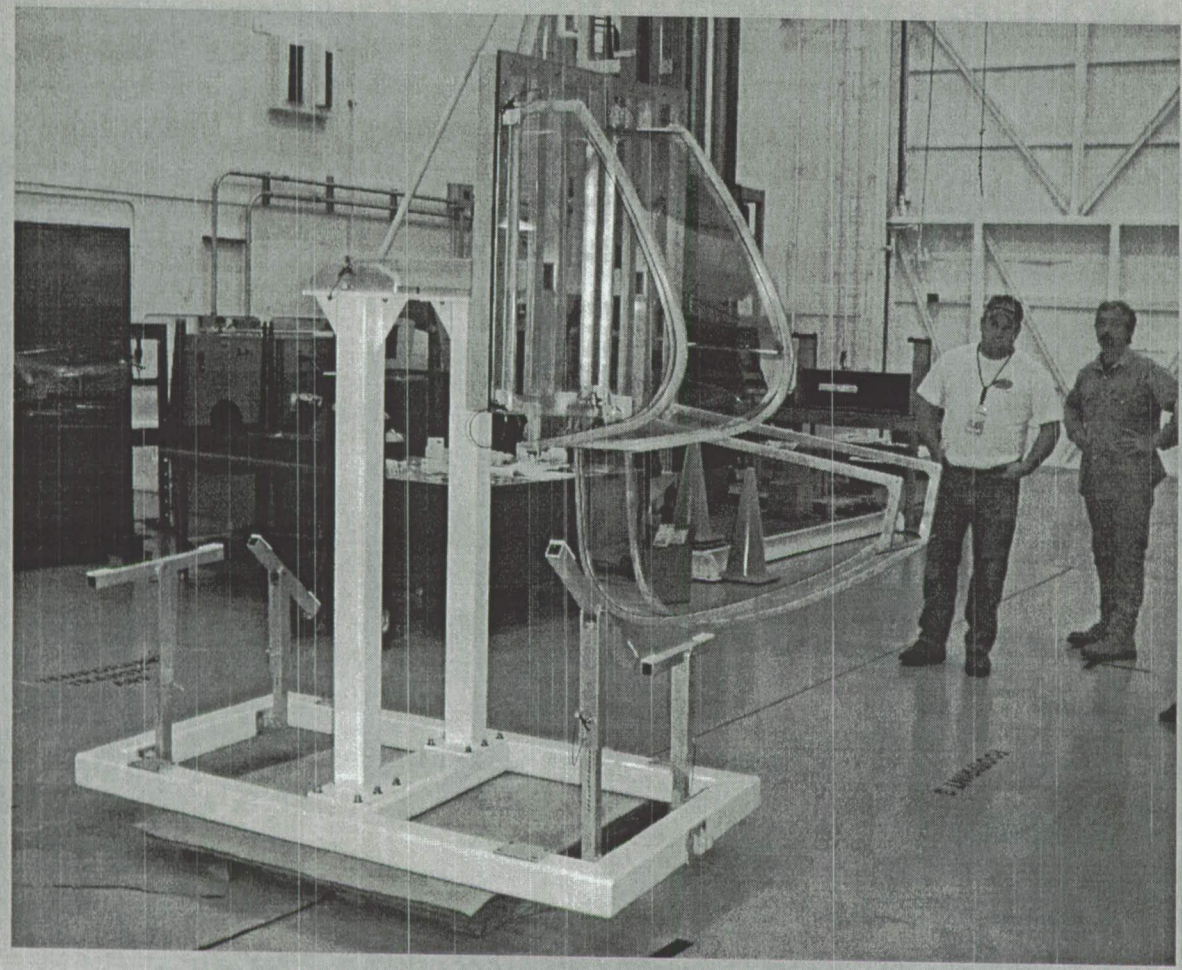

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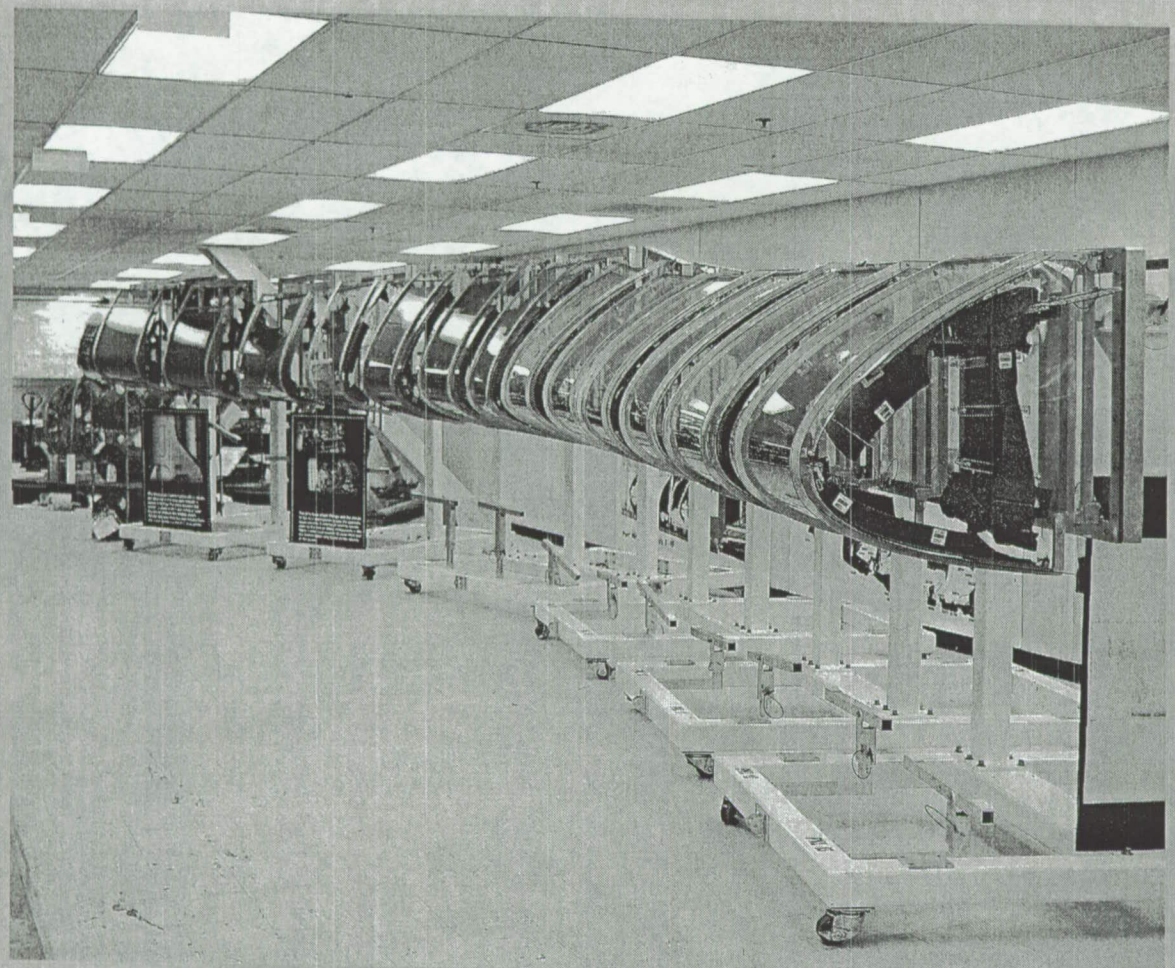

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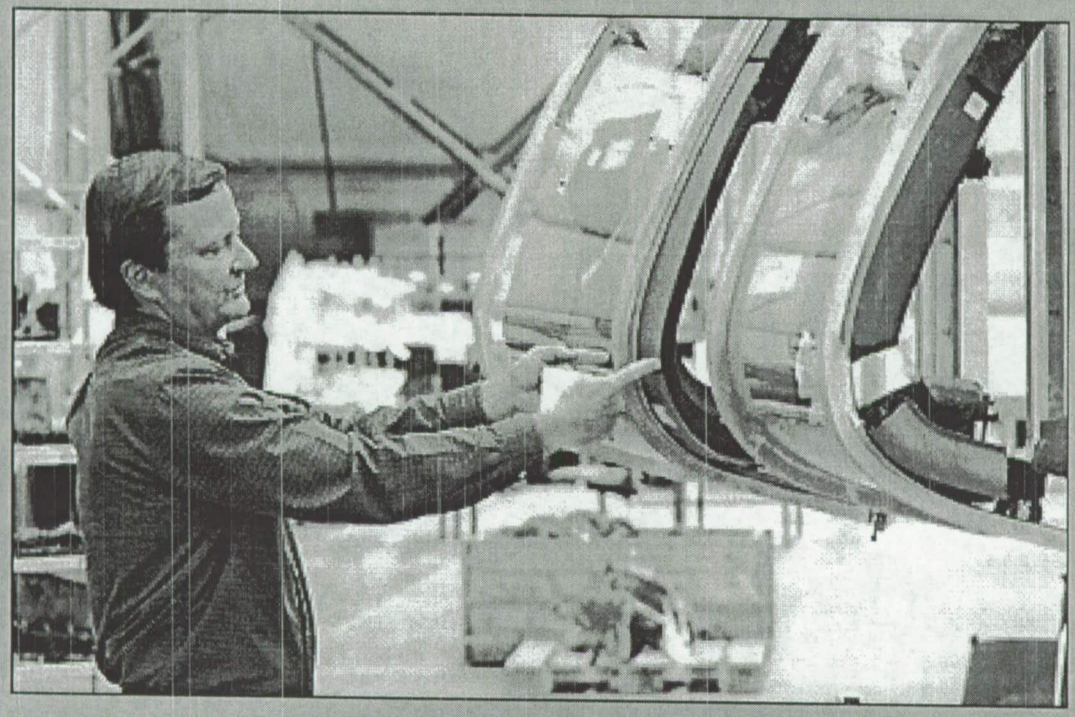

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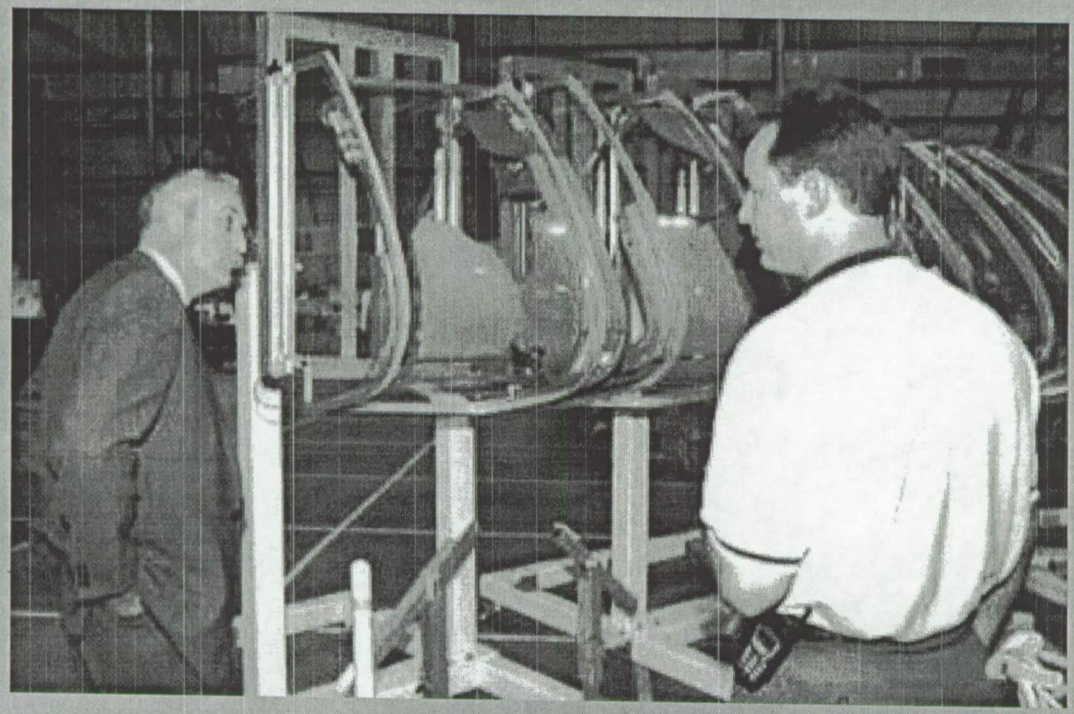

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